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Precision Automatic Co-Registration Procedures for NASA Sensors

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TOPICS

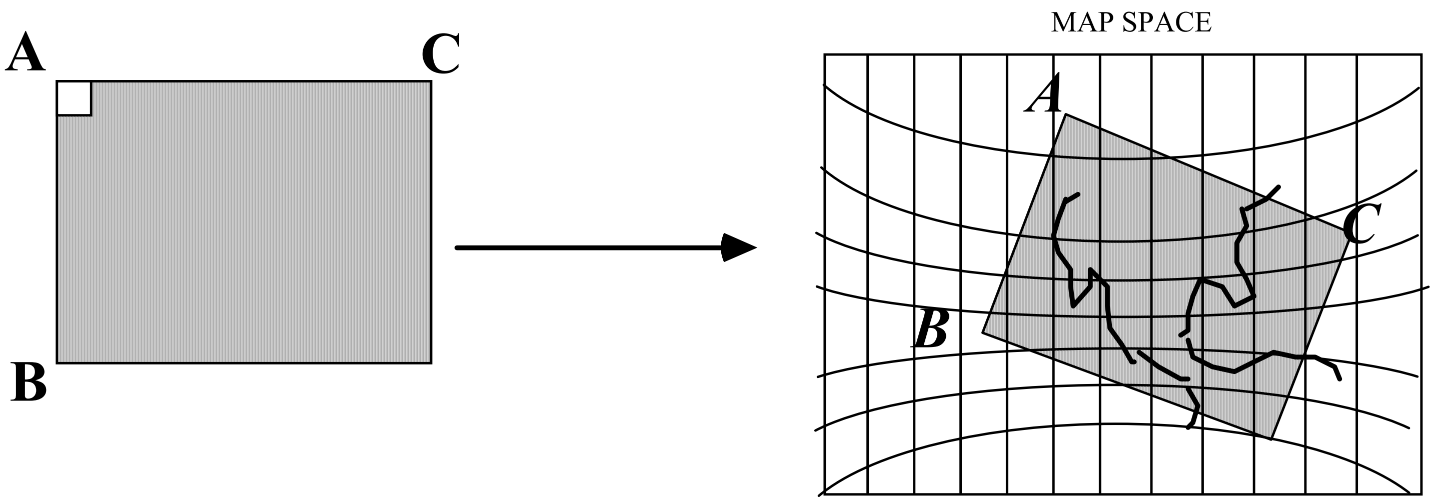
- Utility & Applicability of Approach
- Essential Algorithms & Procedures
  - GeoTIFF Label Embedding
  - Tiepoint Matching with 2-D FFT Image Correlation
  - Ultra-Fine Grid Approach
  - Composed Grid Concept
- Image Co-Registration Processing Examples

Utility & Applicability of Approach

- Automatic label reading of image ephemeredes permits batch processing once procedure validated
- Process provides a systematic approach to removing elevation offset effects, important with higher resolution sensors (<1000m/pixel)
- Process iteratively analyses tiepoint co-registration sources of error commonly found in earth imagery
- Supports applications of current interest:
  - Change detection, GIS ingest, time series analysis

Essential Algorithms & Procedures:
(1) GeoTIFF Label Embedding

Raster Data is often related to Map/Model space
by simple rotation, translation and scaling.



GeoTIFF Georeferencing Tag Descriptions

- ModelTiePointTag: This tag stores raster-to-model tiepoint pairs in the order (I,J,K, X,Y,Z...), where (I,J,K) is the point at location (I,J) in raster space with pixel-value K, and (X,Y,Z) is a vector in model space. A single tiepoint, together with the PixelScale tag (below), completely determines the relationship between raster and model space, provided the raster image is ortho-corrected to the map projection geometry of the model space.

- ModelPixelScaleTag: This tag is provided for defining linear, non-rotated transformations between raster and model space. The tag consists of the three DOUBLE format values (ScaleX, ScaleY, ScaleZ), where ScaleX and ScaleY give the horizontal and vertical spacing of the raster pixels. The ScaleZ is primarily used to map the pixel value of a digital elevation model into the correct Z-scale.

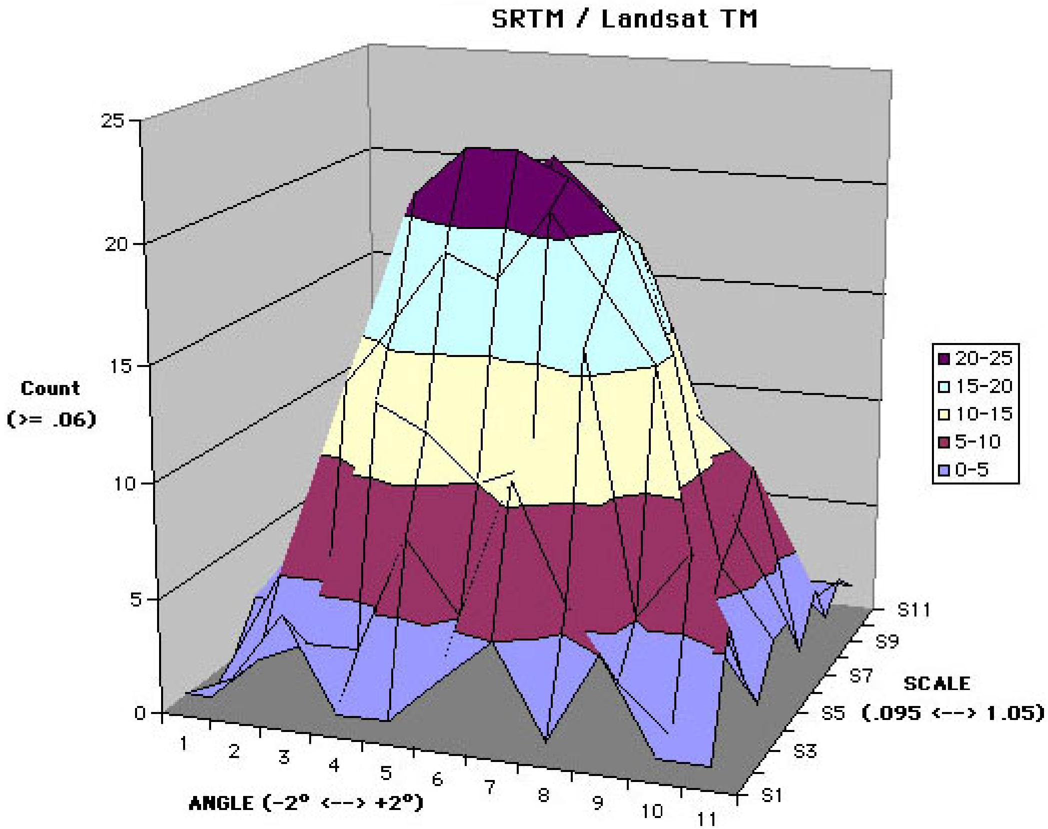
- ModelTransformationTag: This tag provided for defining exact linear (affine) transformations between raster and model space. The ModelTransformationTag may be used to specify the 3D transformation matrix and offset between the raster space (and its dependent pixel-value space) and the (possibly 3D) model space.

Essential Algorithms & Procedures:
(2) Tiepoint Matching with 2-D FFT Image Correlation

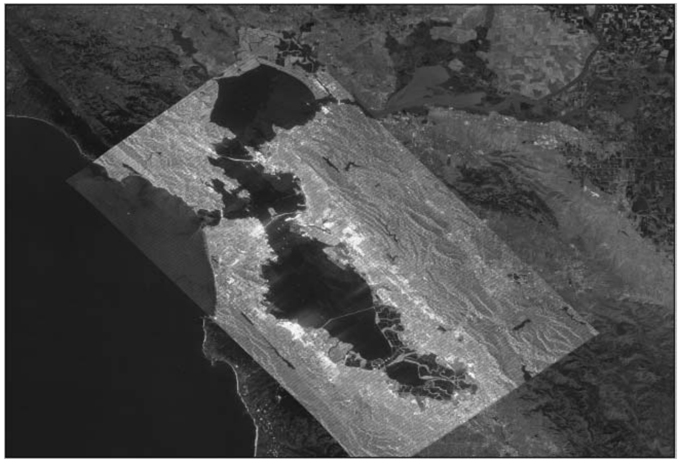
- Supports four dimensional search (lateral,vertical,scale, rotation)
- Dynamic allocation to allow FFT of any size, not just 32 x 32
- GeoTIFF labels model the matching of the two input images including
- - rotation to any angle
- - scale difference
- Magnify parameter allows adjustment to best scale of correlation and a hierarchical approach
- Subpixel correlation
- All reprogrammed in C, including RFT2

Tiepoint Positioning Sensitivity With Phase Correlation Image Alignment Method

(SRTM-to-Landsat Co-Registration: Scale & Rotation)



SRTM co-registered to Landsat mosaic



Essential Algorithms & Procedures:
(3) Ultra-Fine Grid Approach

- **Types of correction that can be gridded:**
  - Instrument data logger (ephemeris file)
  - Map reprojection
  - Control points from autocorrelation (PICMATCH)
  - Elevation offset (ray-tracing)
- **Suite of routines developed for the ultrafine grid file format**
  - Map reprojection (GTPROJ)
  - Arithmetic (MF3)
  - Least squares fit (IBISLSQ2,TIECONV)
  - Finite Element Surface fit (TIECONV)
    - Linear, Bi-linear, Quadratic, Cubic added as options
  - Analyst-friendly procedures with GeoTIFF labels embedded simplify process and help avoid errors

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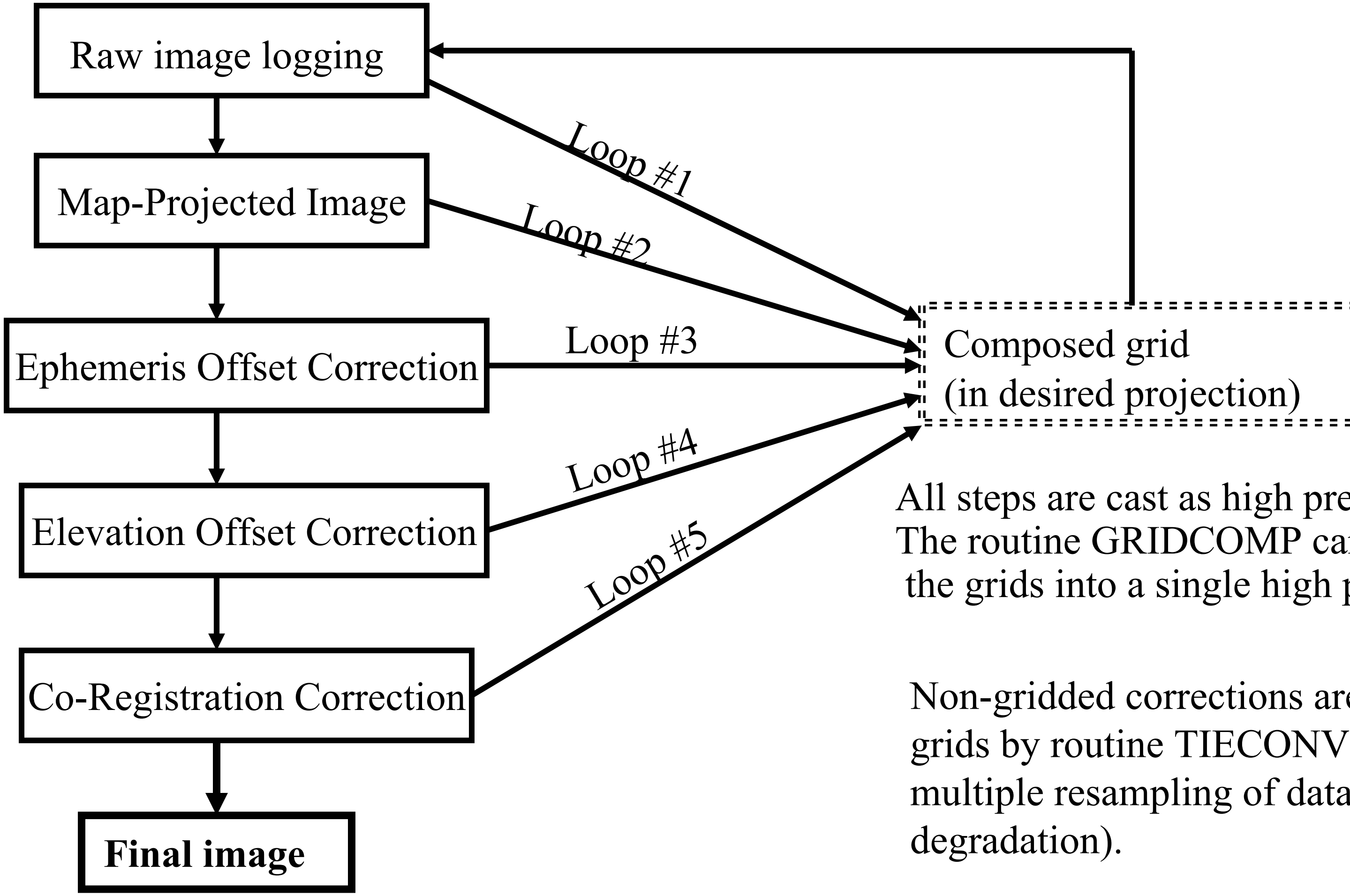
Speed & Error Analysis of 5 x 5 pixel Ultrafine Gridding Case

- Assume 3000 x 3000 image with max deviation from affine of 300 pixels

Grid size	Max error	raytrace speedup	cell size
1 x 1	300	9000000	3000
➔ 30 x 30	.333	10000	100
300 x 300	.00333	100	10
600 x 600	.0008333	25	5
3000 x 3000	.0000333	1	1

Essential Algorithms & Procedures: (4) Composed Grid Concept

Correction steps
(application dependent)



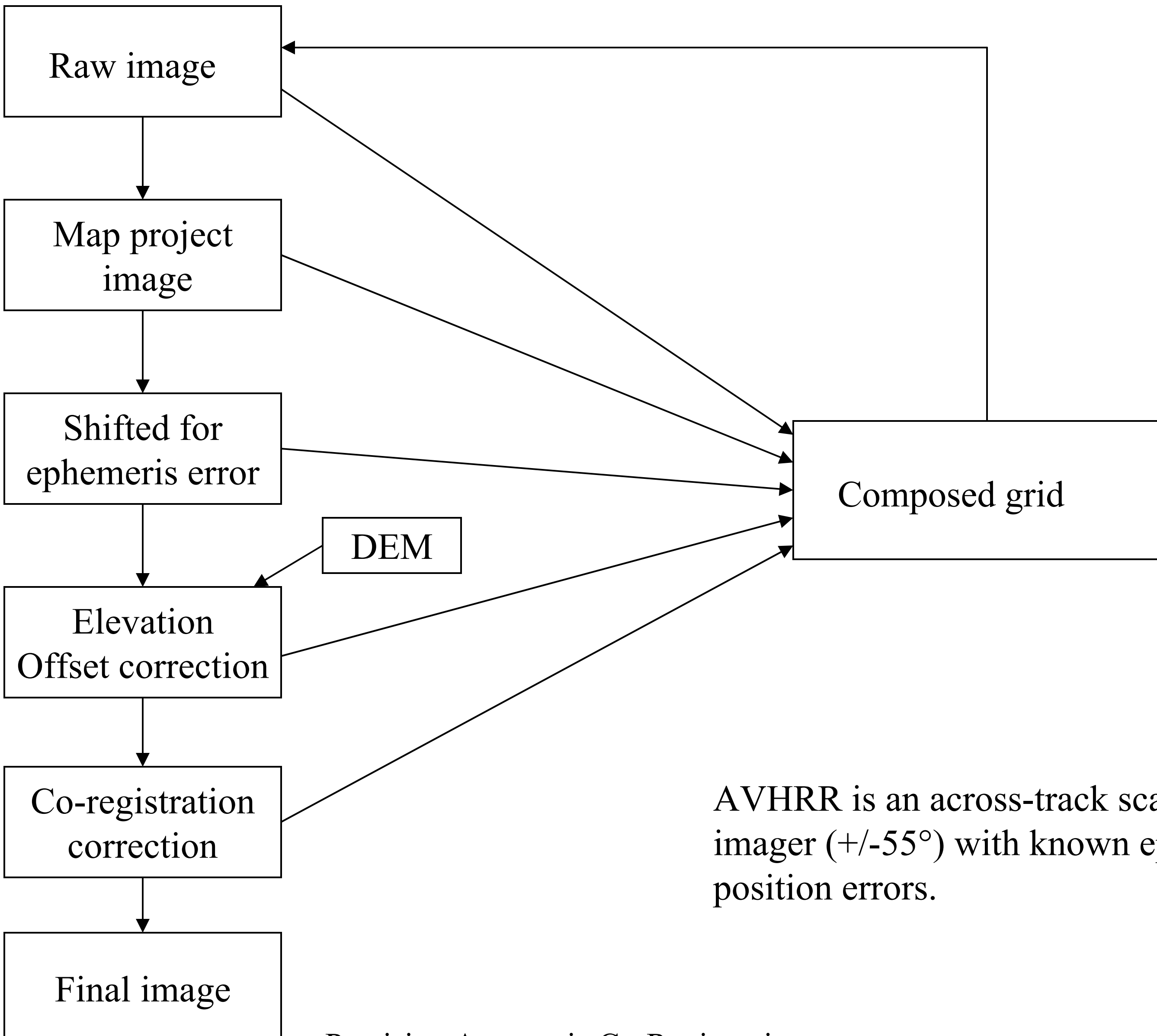
All steps are cast as high precision grids. The routine GRIDCOMP can Compose the grids into a single high precision grid.

Non-gridded corrections are converted to grids by routine TIECONV. This avoids multiple resampling of data (a source of degradation).

AVHRR Co-Registration Case

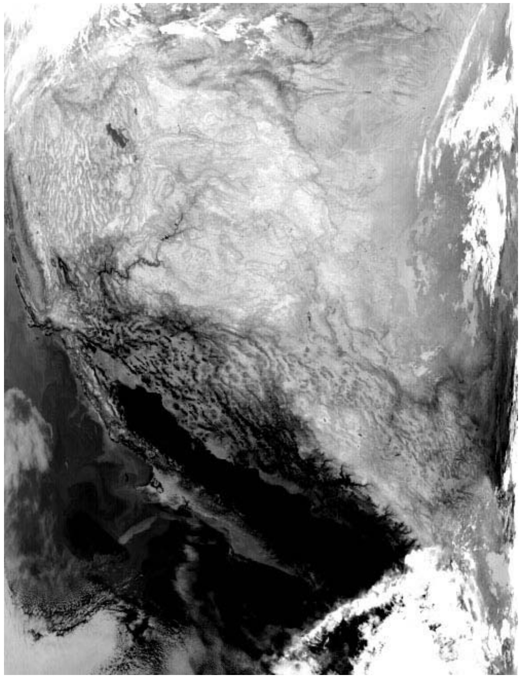
- Steps:
  - Map Project Image using sensor scan characteristics and spacecraft position information
  - Co-register tiepoints in image to master Landsat orthorectified mosaic database
  - Using an elevation model, ray-trace correct for horizontal shifts caused by terrain and sensor view angle
  - Re-calculate tiepoints to adjust for spacecraft roll, pitch, yaw not explicitly removed by producer’s Level-1 processing
  - Project to desired projection for area of interest as required

AVHRR Co-Registration Case: Concept

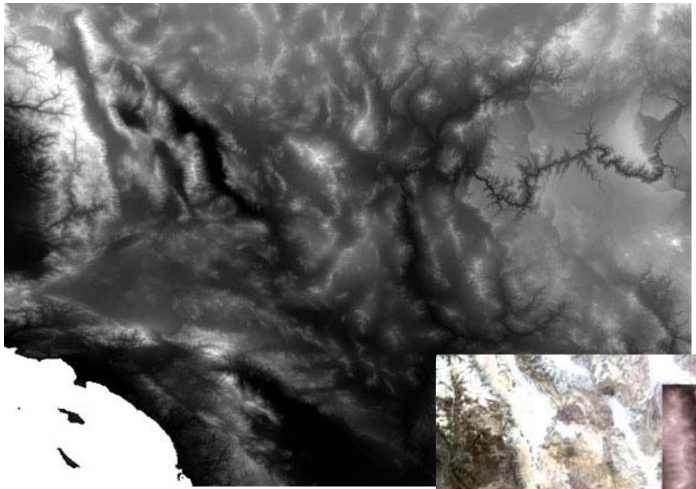


AVHRR is an across-track scanning imager (+/-55°) with known ephemeris position errors.

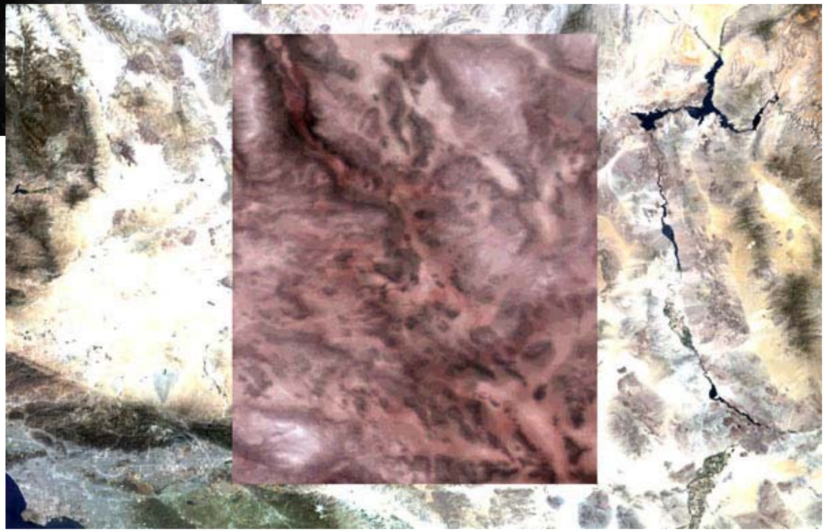
Raw AVHRR



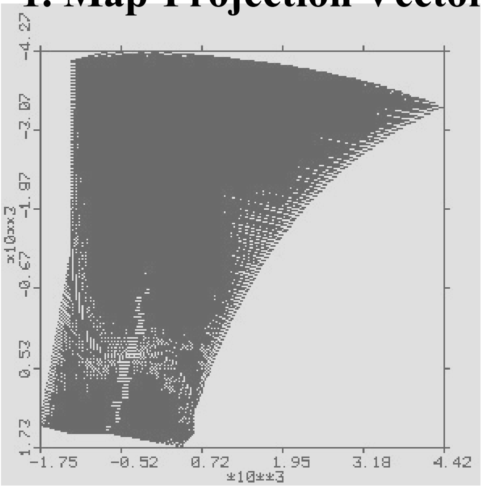
Elevation File



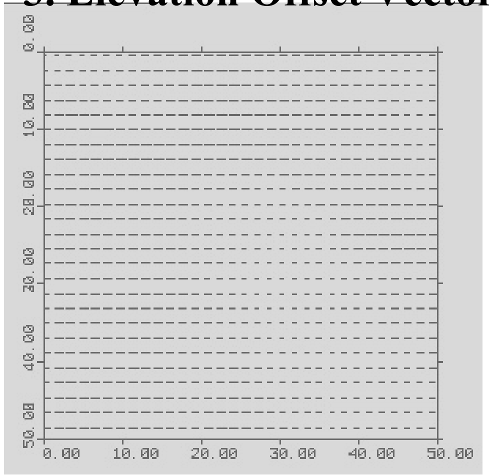
AVHRR Co-Registered To TM Mosaic



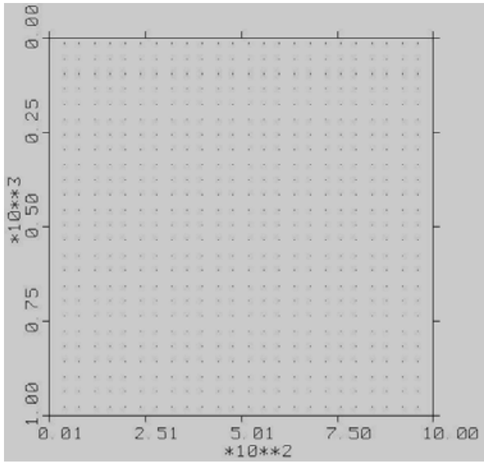
1. Map-Projection Vectors



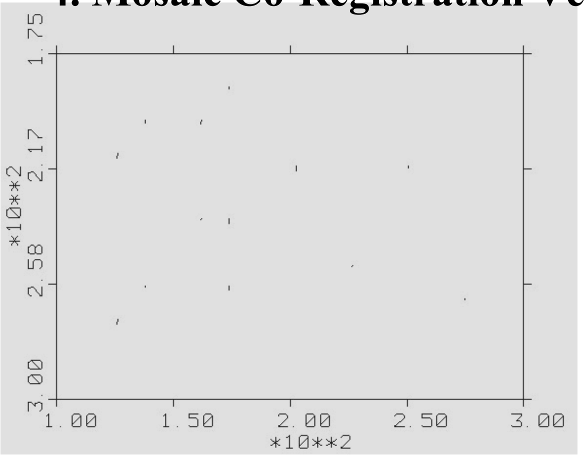
3. Elevation Offset Vectors



2. Ephemeris Shift Vectors



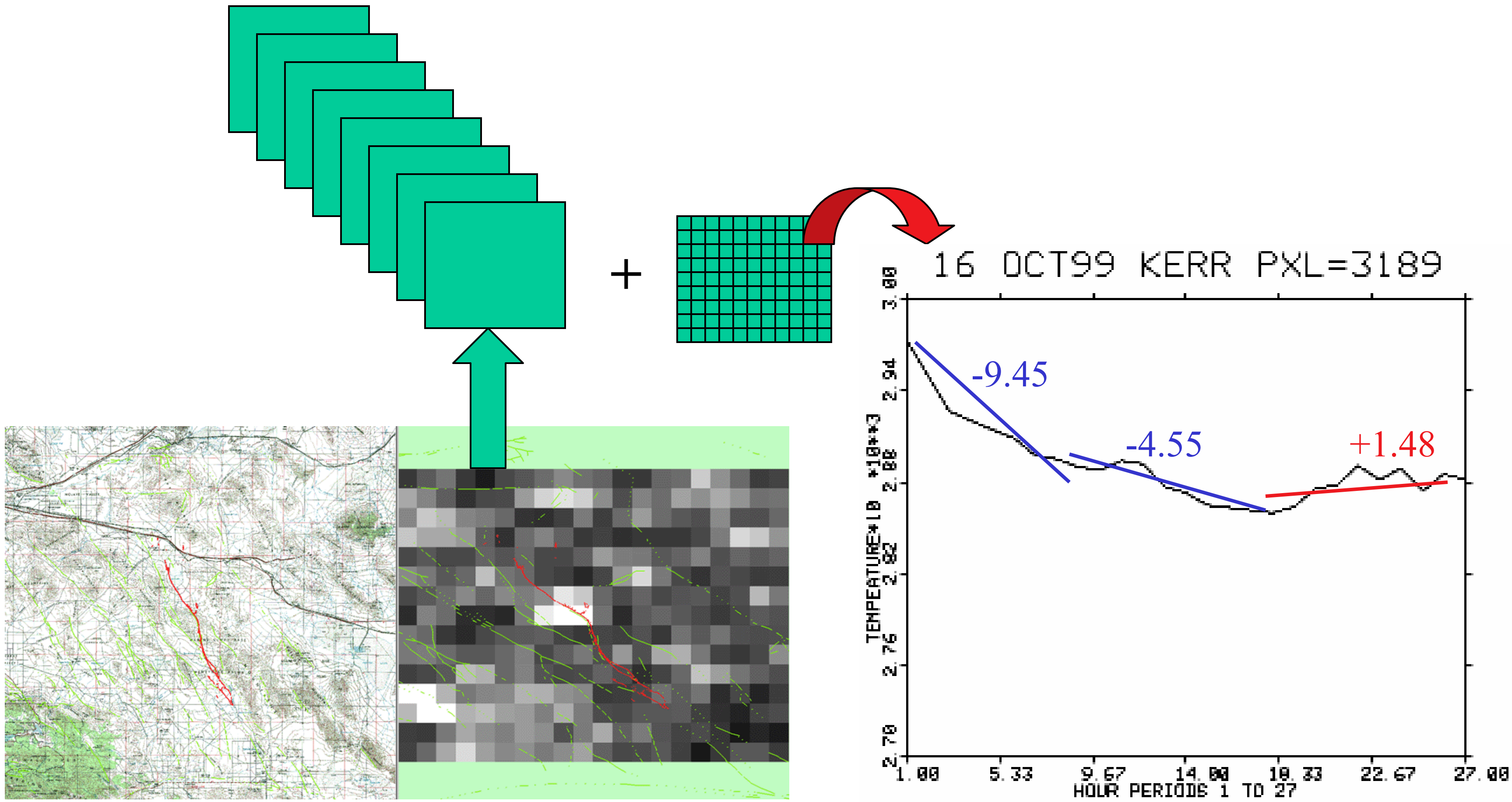
4. Mosaic Co-Registration Vectors



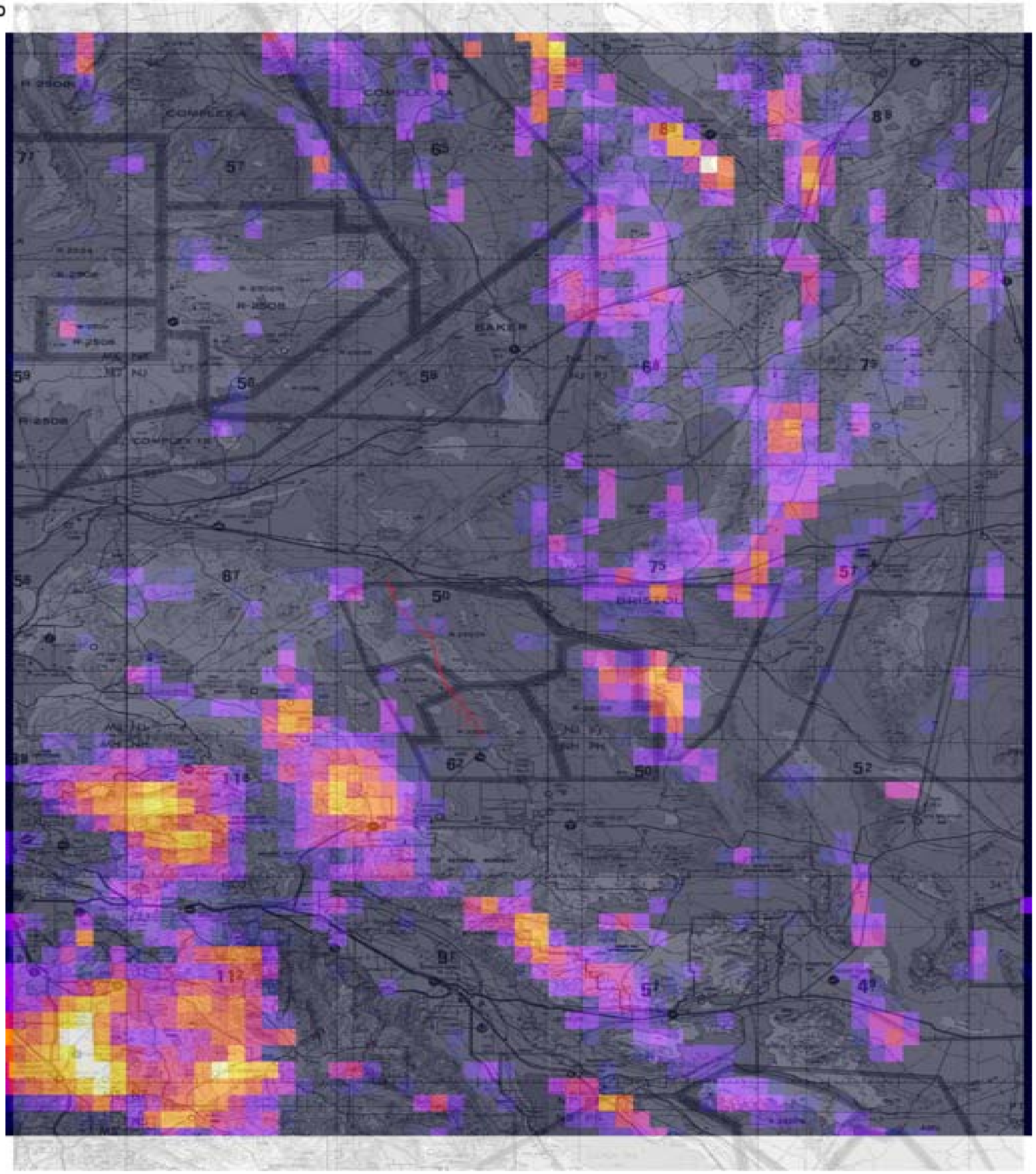
GOES Co-Registration Case

- Steps:
  - Map Project Image using sensor scan characteristics and spacecraft position information
  - Co-register tiepoints in image to master Landsat orthorectified mosaic database
  - Re-calculate tiepoints to adjust for spacecraft roll, pitch, yaw not explicitly removed by producer’s Level-1 processing
  - Project to desired projection for area of interest as required
  - Analyse time series as desired

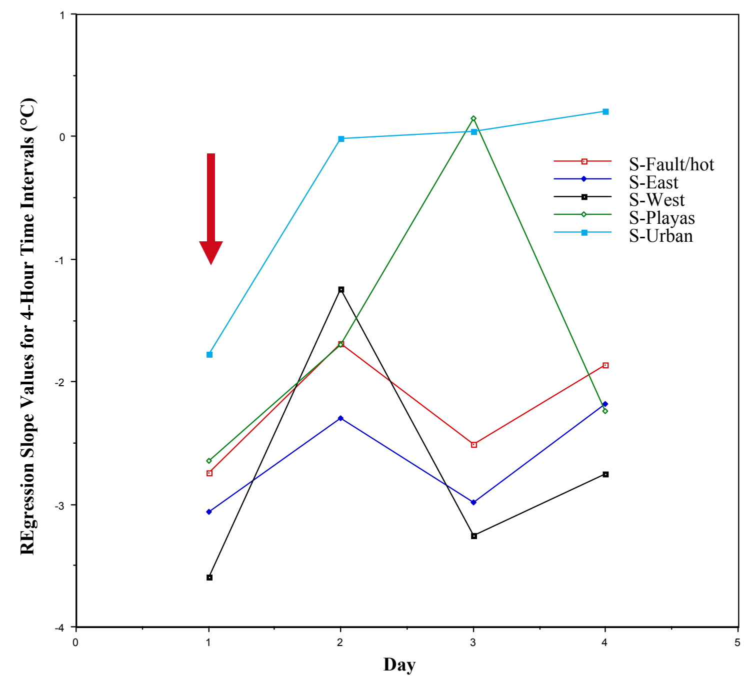
GOES Co-Registration Case: Processing Steps Diagram



GOES Thermal Anomaly Detection



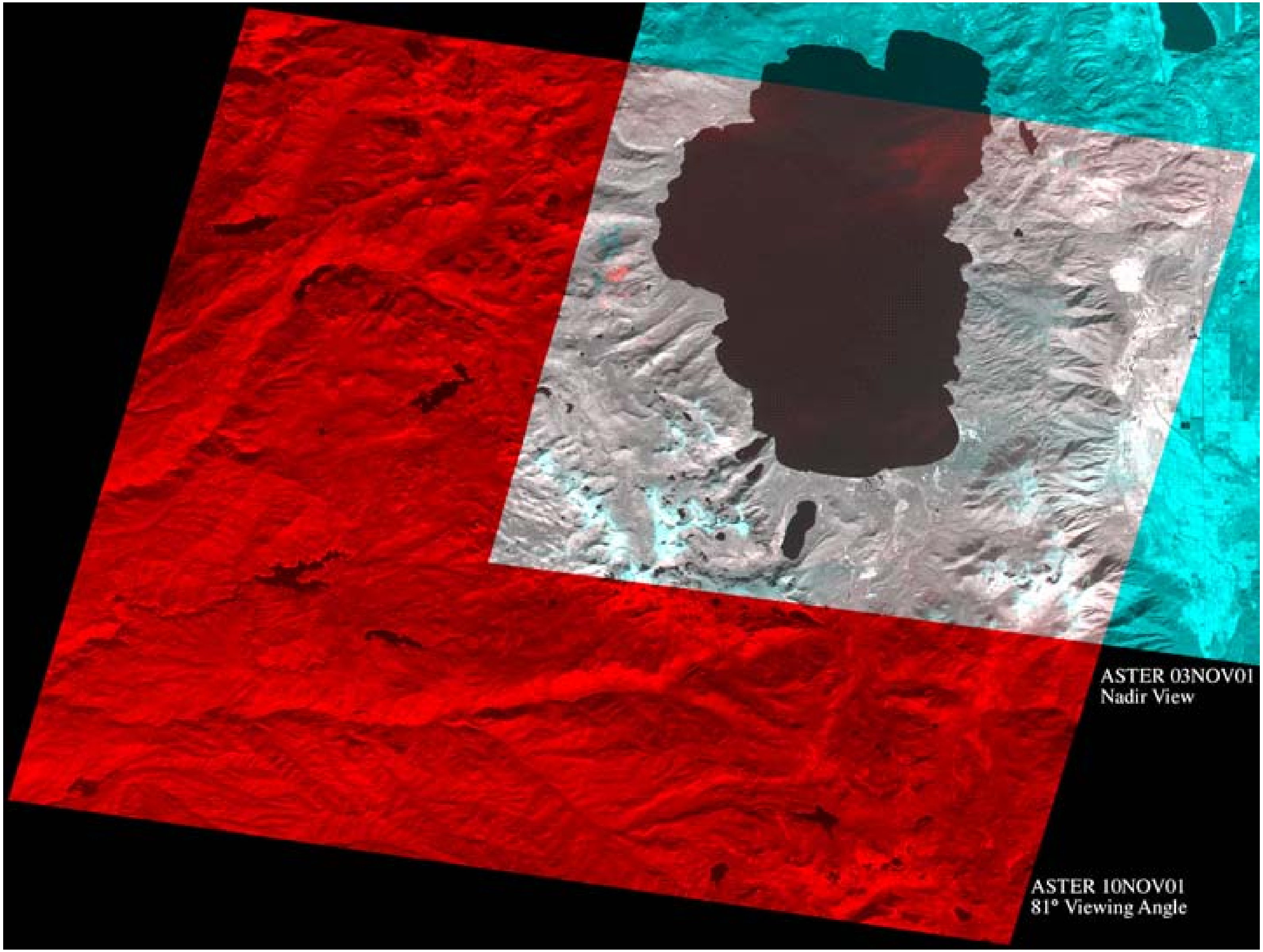
Comparison of GOES Thermal Trends by Land Cover Type



ASTER Co-Registration Case

- Steps:
  - Map Project Image using 11x11 tiepoint array provided from rotated UTM to Platte Carre'
  - Co-register tiepoints in image to master Landsat orthorectified mosaic database using a median elevation height for the scene
  - Using an elevation model, ray-trace correct for horizontal shifts caused by terrain and sensor view angle
  - Identify first ASTER image as the Master, co-register subsequent images to the master. Master should be nadir view
  - Project to desired projection for area of interest as required

ASTER Co-Registration Case: Example



ASTER Co-Registration Case

Example-1
Detail

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ASTER Co-Registration: Example 2

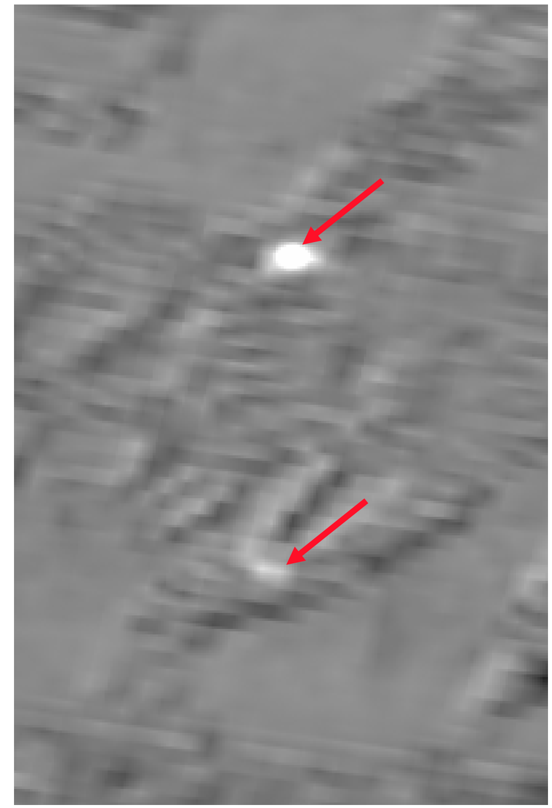
Differencing with 90m *ASTER* Thermal Imagery Reveals Hot Spots

ASTER 08DEC01
THERMAL BAND 13
(90 METER RES)

–

ASTER 24DEC01
THERMAL BAND 13
(90 METER RES)

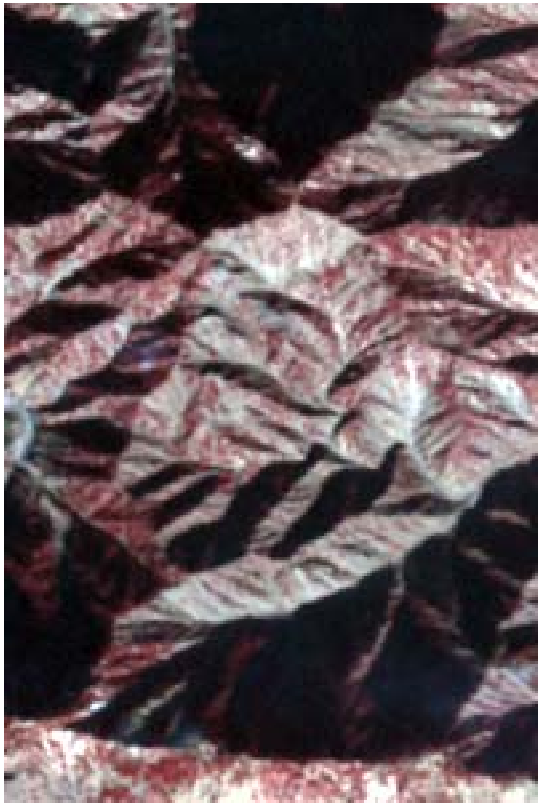
=



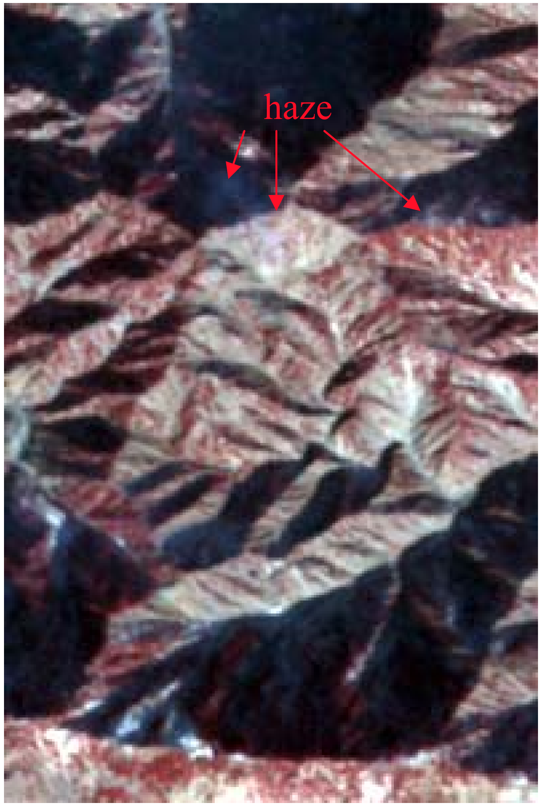
DIFFERENCE SHOWS
HOT SPOTS

ASTER Co-Registration: Example 2

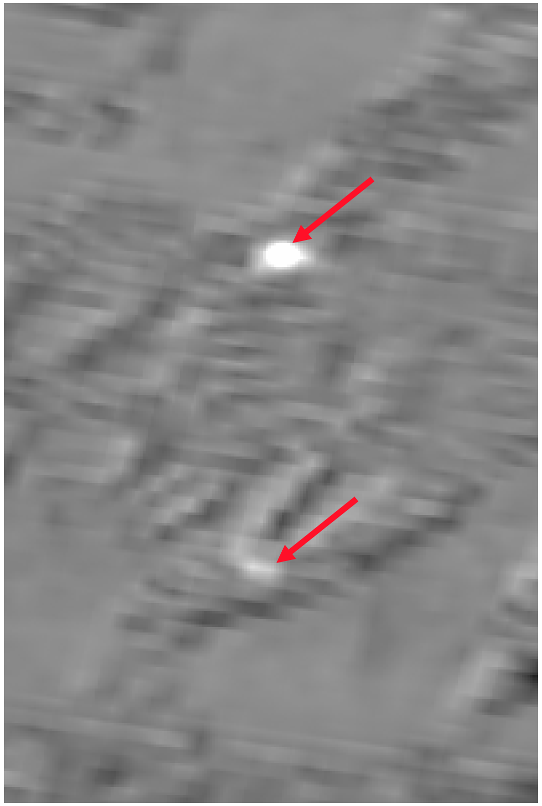
Differencing with 15m *ASTER* VNIR Imagery Reveals Haze



ASTER 08DEC01
VNIR 15m BANDS 1,2,3



ASTER 24DEC01
VNIR 15m BANDS 1,2,3

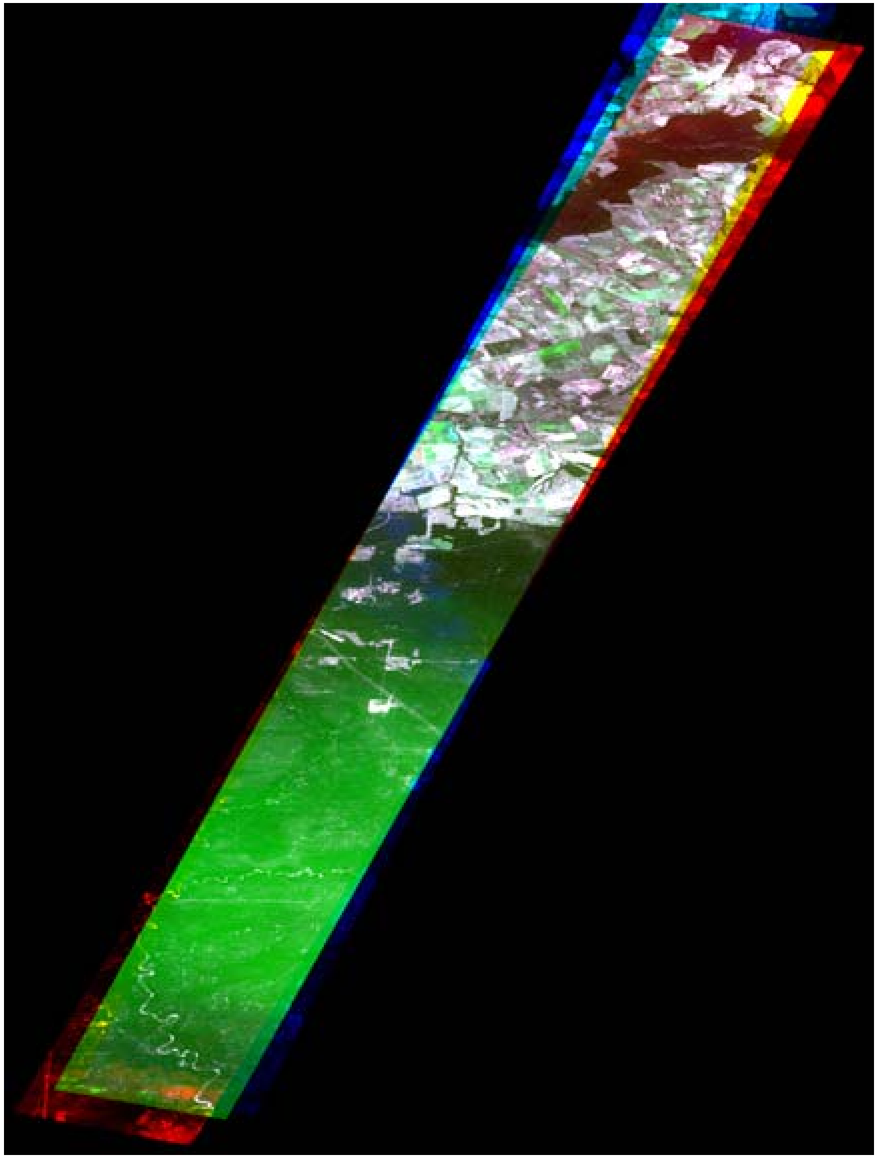


THERMAL
DIFFERENCE IMAGE

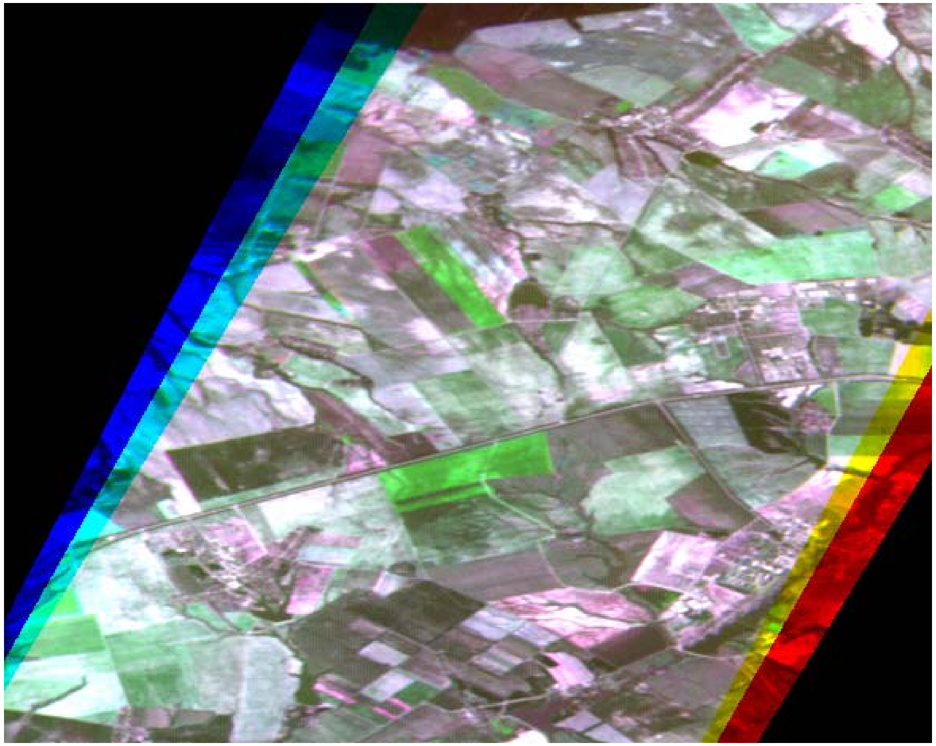
Hyperion Co-Registration Case

- Steps:
  - Map Project Image using four corner tiepoints provided from rotated UTM to Platte Carre'
  - Co-register tiepoints in image to master Landsat orthorectified mosaic database using a median elevation height for the scene
  - Using an elevation model, ray-trace correct for horizontal shifts caused by terrain and sensor view angle
  - Identify first *Hyperion* image as the Master, co-register subsequent images to the master. Master should be nadir view
  - Project to desired projection for area of interest as required

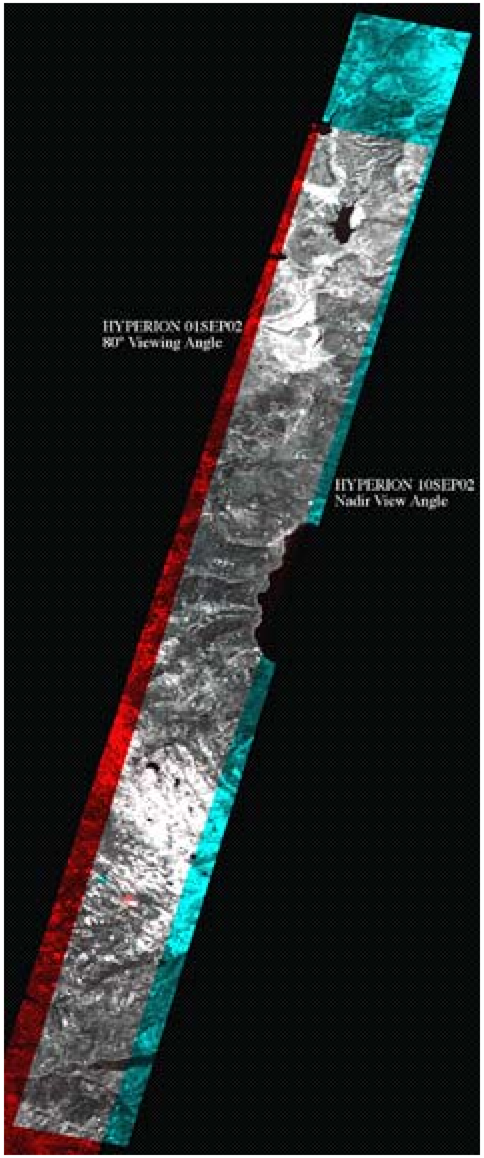
Hyperion Co-Registration Case: Example-1



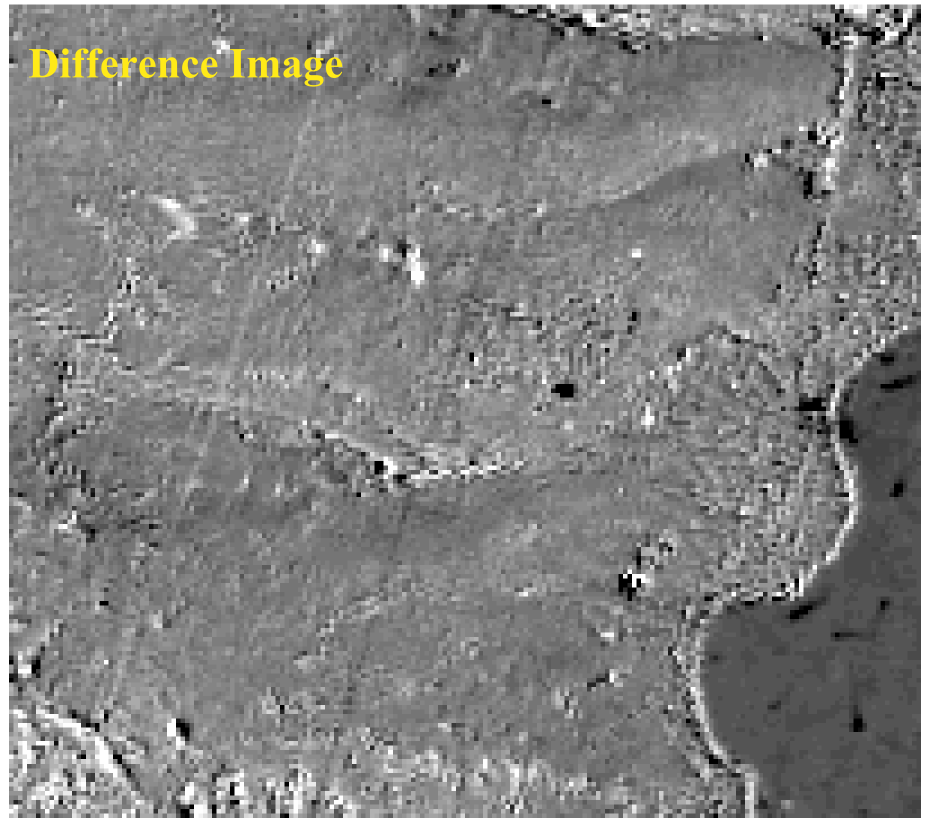
Three Images, Low-Level Terrain



Hyperion Co-Registration Case: Example-2



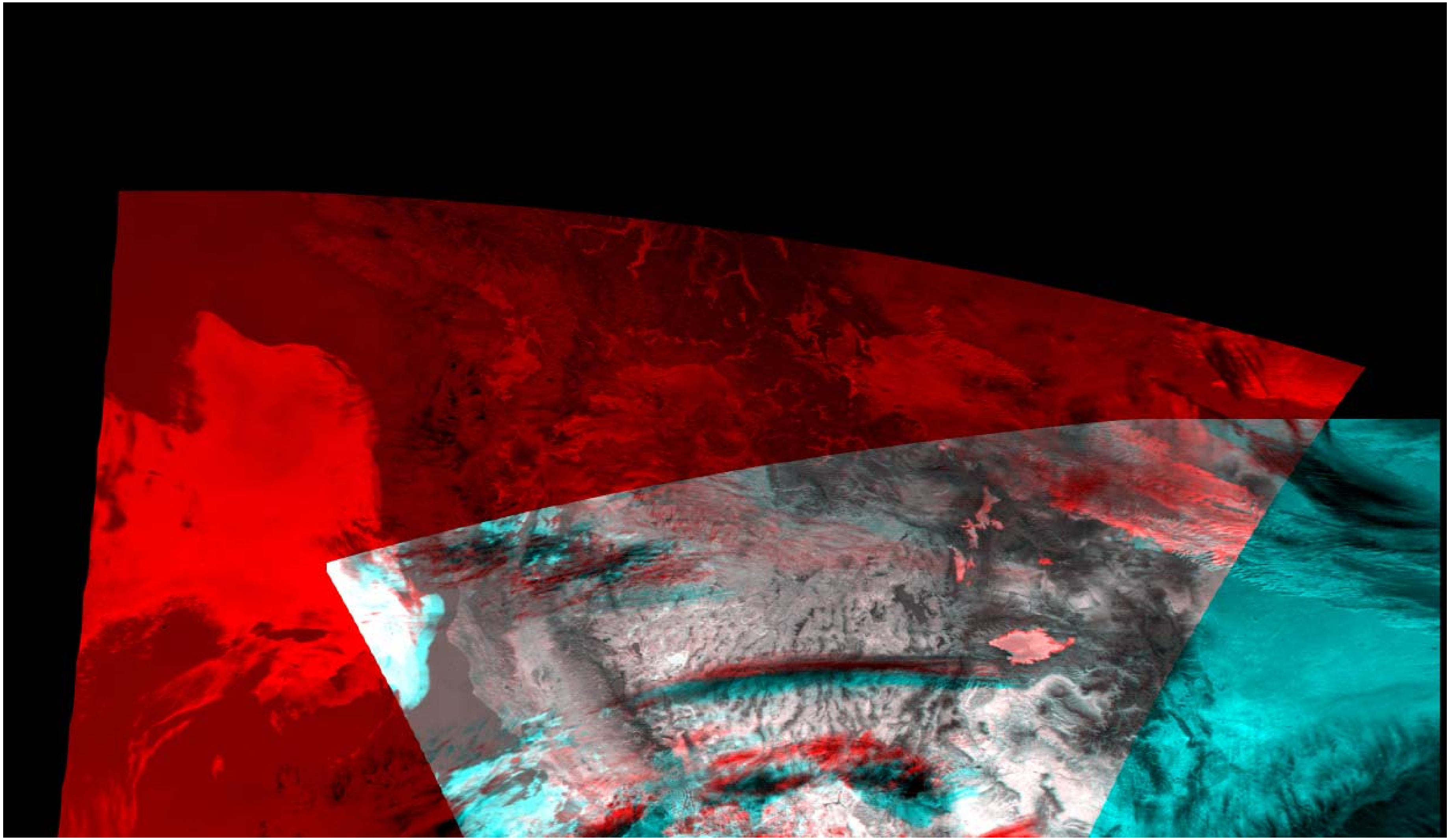
Two Images, Strong Relief



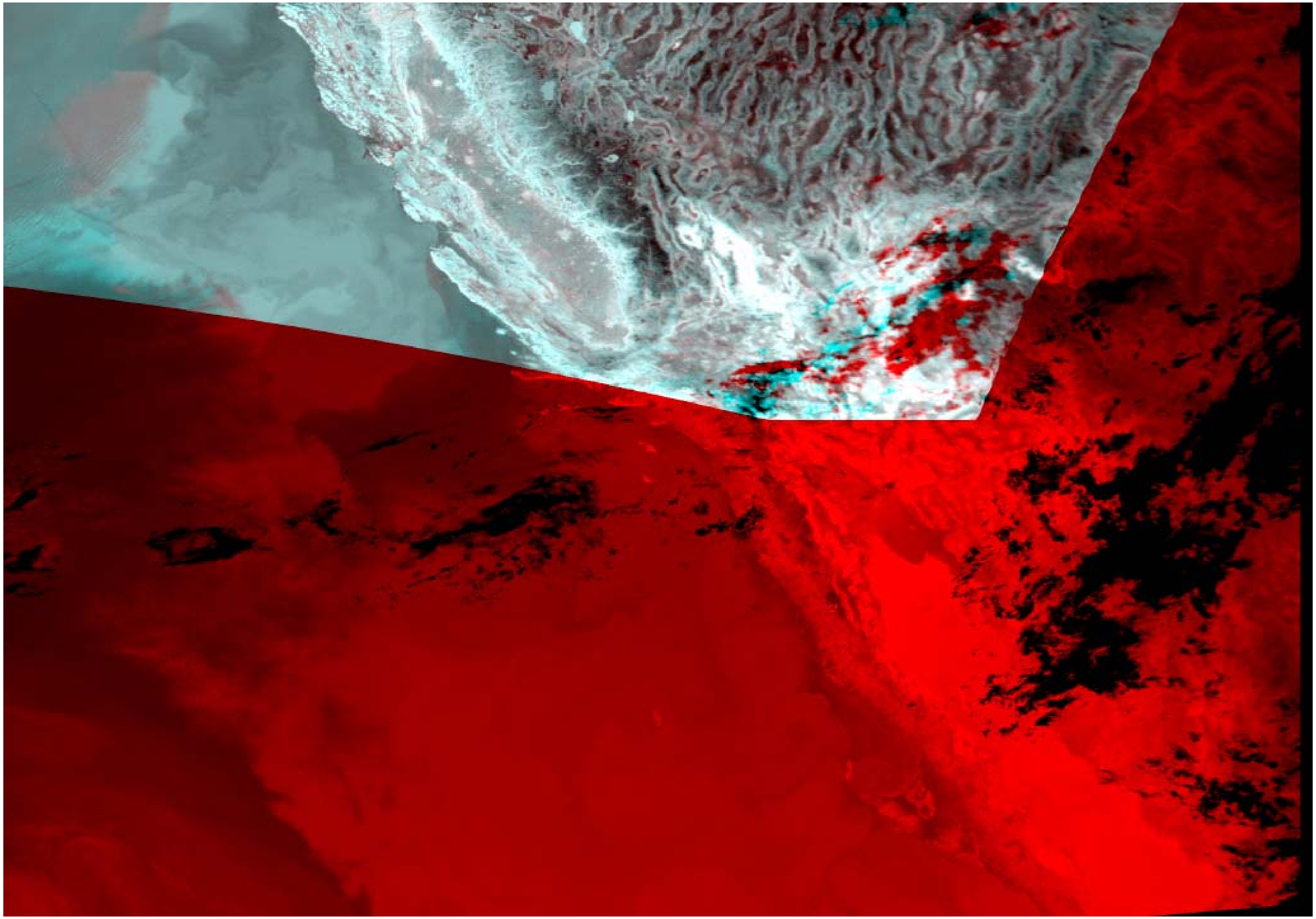
MODIS *Terra* & *Aqua* Co-Registration Case

- Steps:
  - Map Project Image using per-pixel lat/long array provided to Platte Carre'
  - Co-register tiepoints in image to master Landsat orthorectified mosaic database using a median elevation height for the scene
  - Using ETOP-05 elevation model, ray-trace correct for horizontal shifts caused by terrain and sensor view angle
  - Identify first MODIS image as the Master, co-register subsequent images to the master.
  - Project to desired projection for area of interest as required

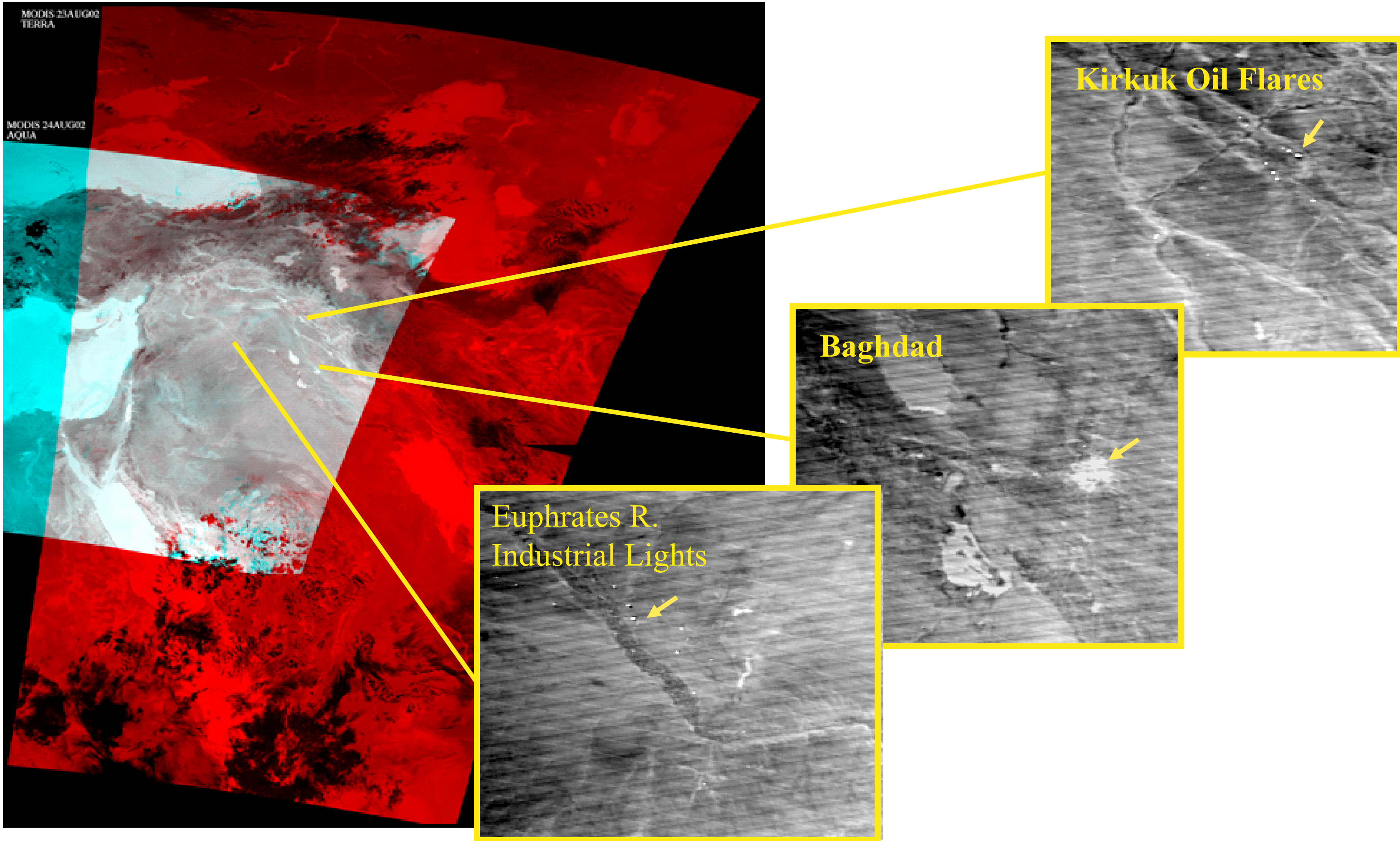
MODIS *Terra* & *Aqua* Co-Registration Case-1: Daytime



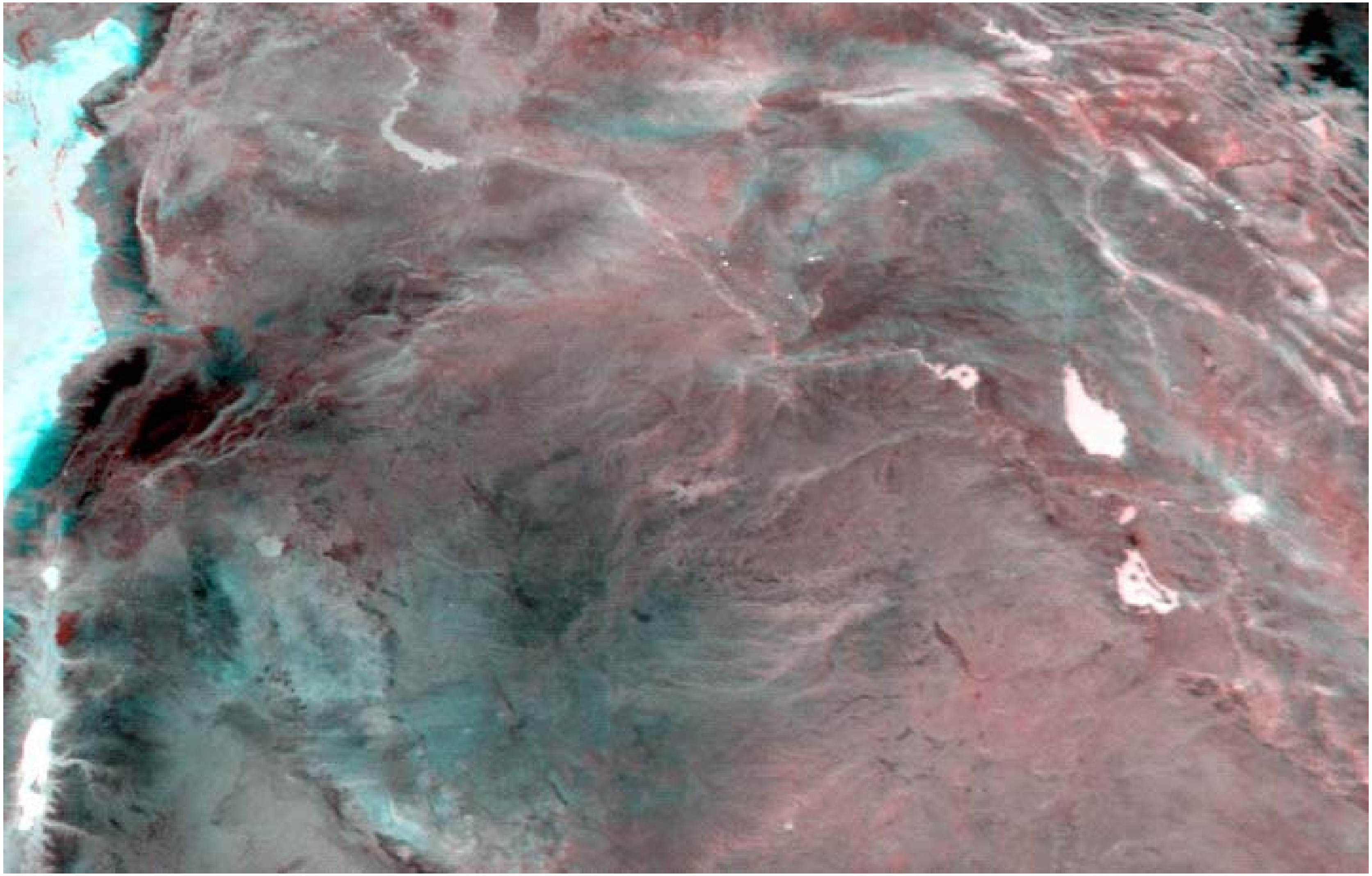
MODIS *Terra* & *Aqua* Co-Registration Case-1: Nighttime



MODIS *Terra* & *Aqua* Thermal Band Co-Registration Case-2



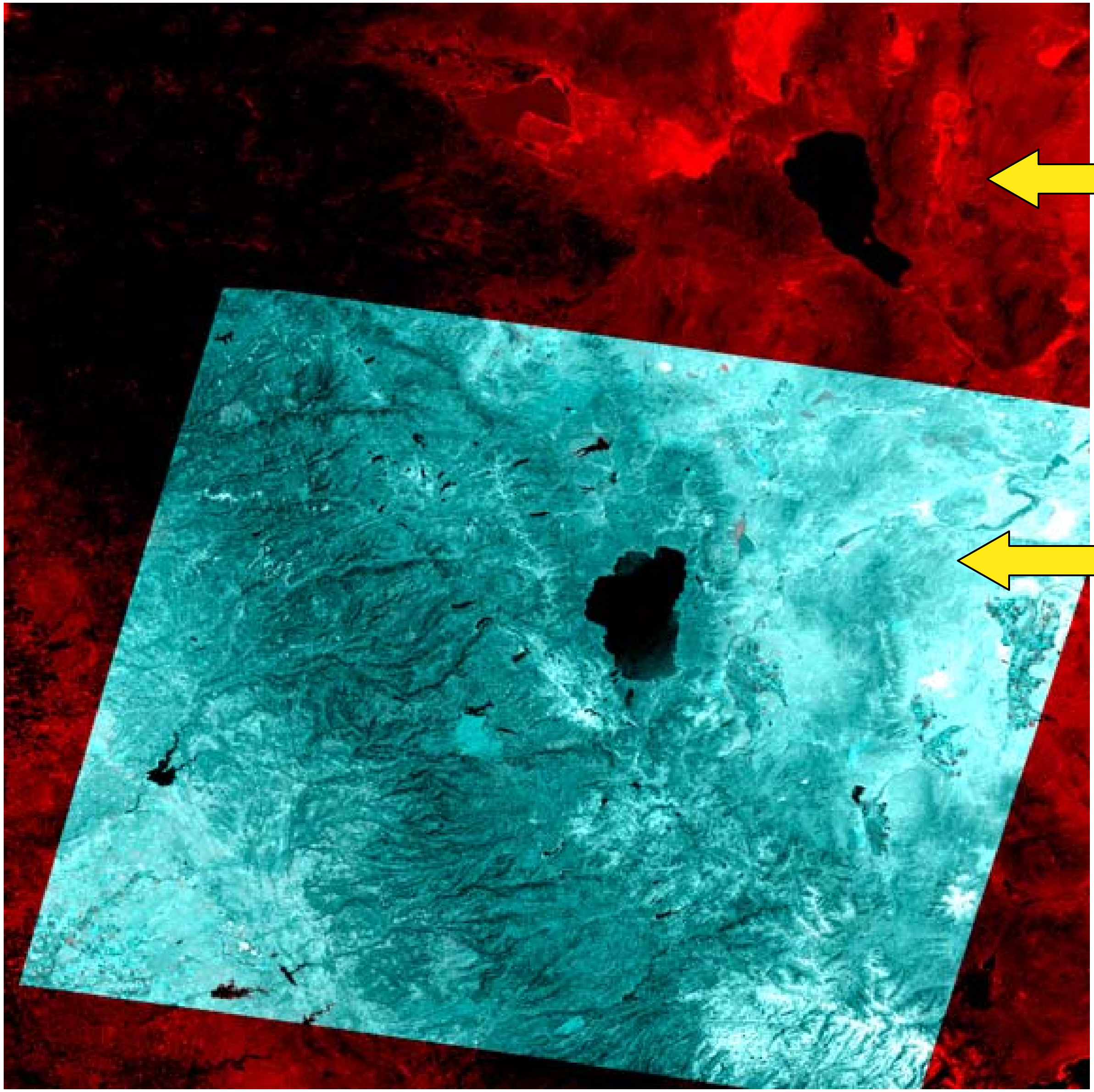
MODIS *Terra & Aqua Thermal Band* Co-Registration Case-2: Detail



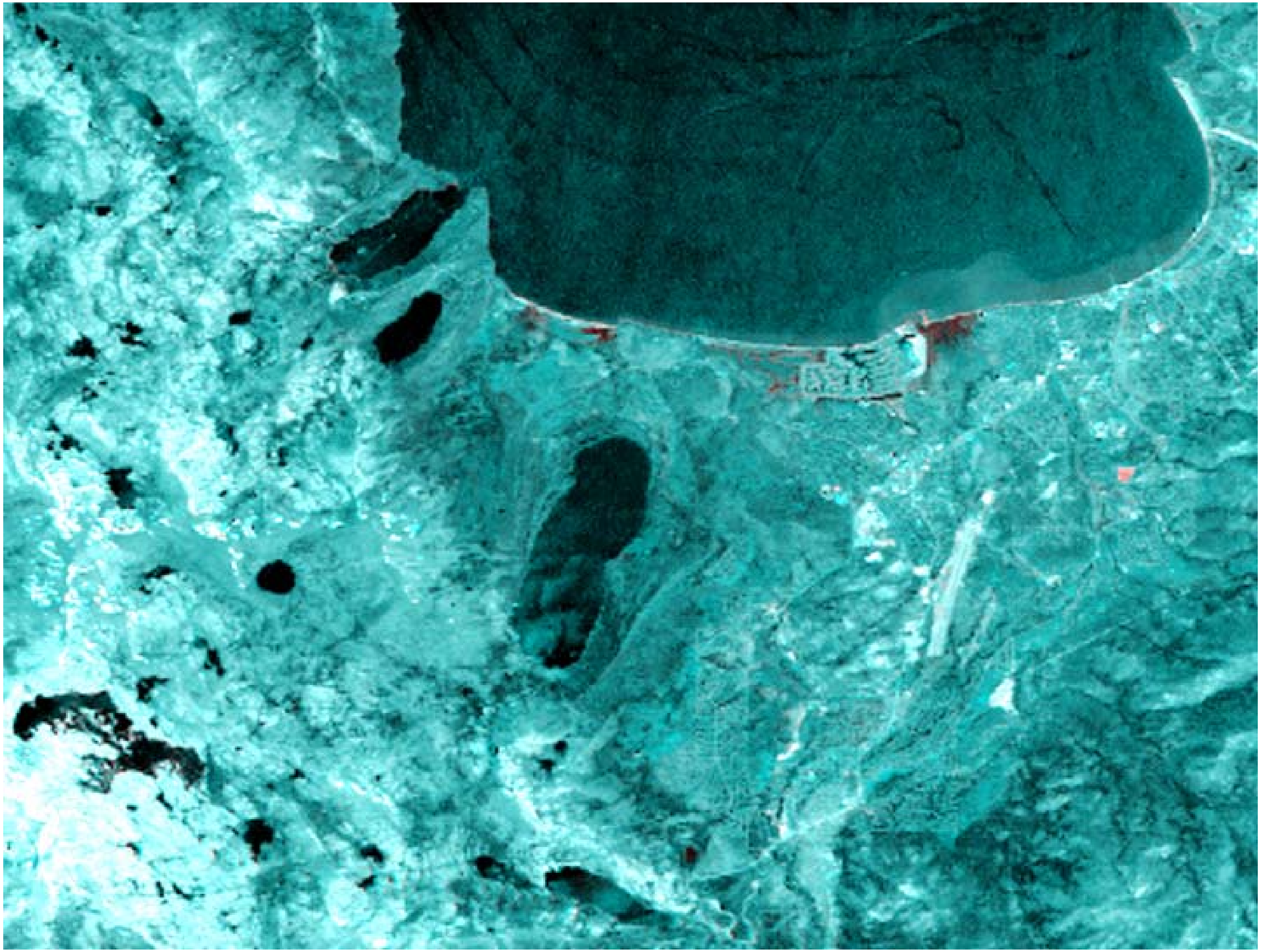
Landsat Co-Registration Case

- Steps:
  - Map Project Image using four corner tiepoints provided from rotated UTM to Platte Carre’
  - Co-register tiepoints in image to master Landsat orthorectified mosaic database using a median elevation height for the scene
  - Using an elevation model, ray-trace correct for horizontal shifts caused by terrain and sensor view angle if not Landsat-7 product
  - Landsat 5/4 images in SOM projection require subsequent tiepoint collection to correct for known ephemeris errors
  - Project to desired projection for area of interest as required

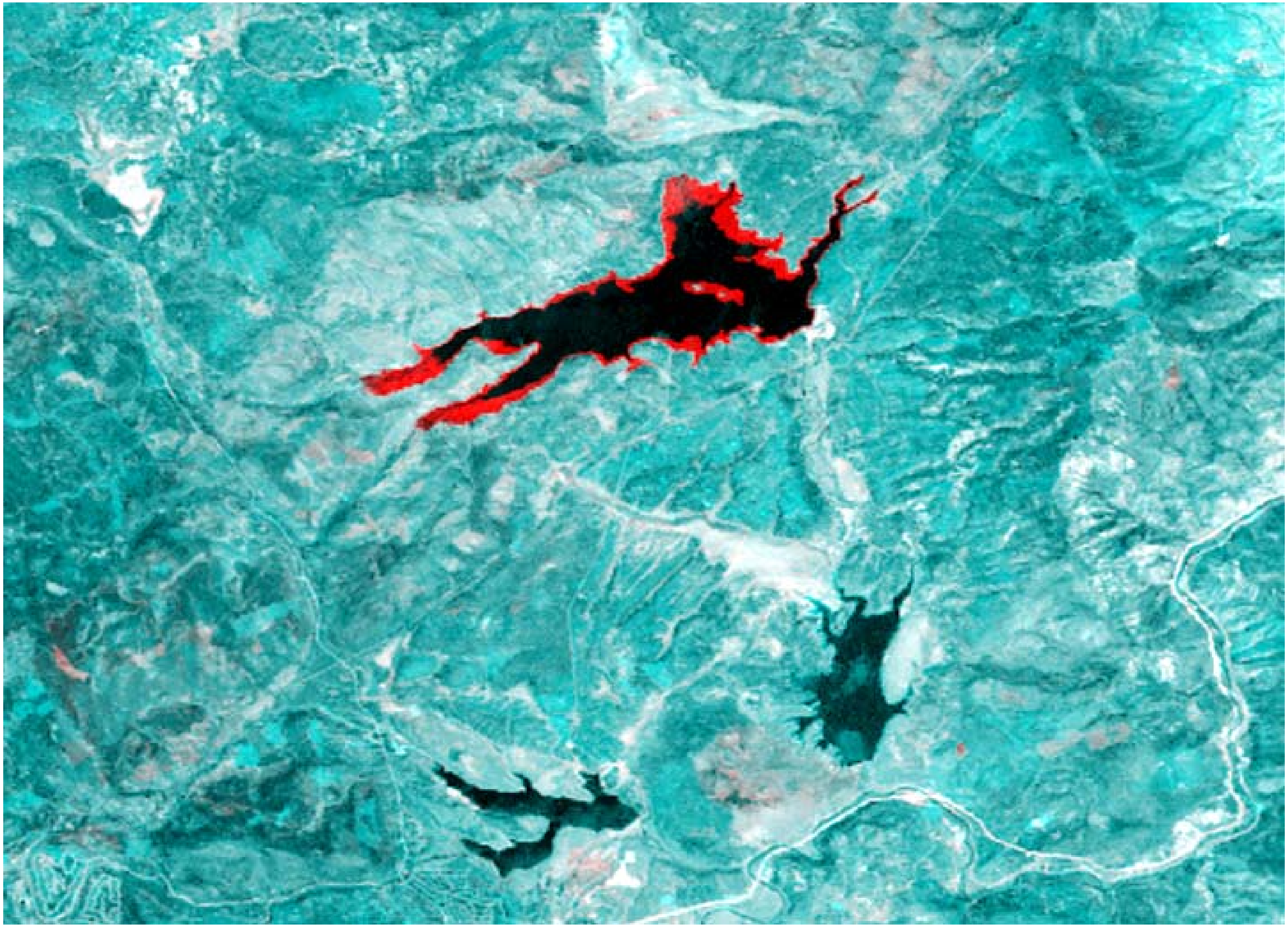
Landsat Co-Registration Case: Example



Landsat Co-Registration Case: Detail-1



Landsat Co-Registration Case: Detail-2



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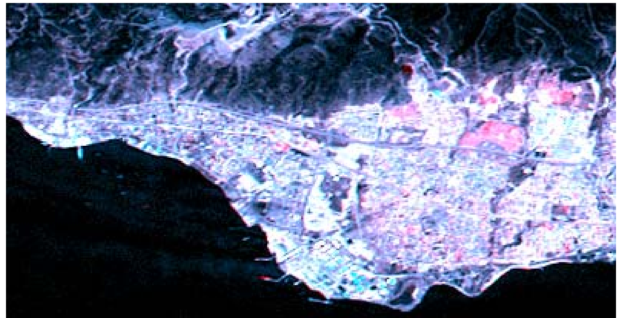
Izmet, Turkey Earthquake of August, 1999 from Co-Registered Landsat

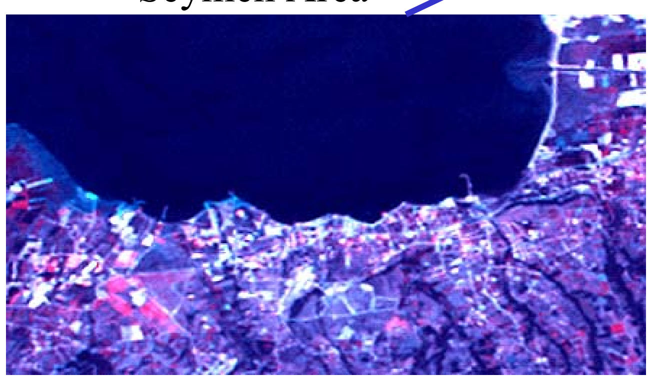
West Derince Area



Overview

Co-Registered Images
August 10, 1999 (pre-earthquake)
September 27, 1999 (post-earthquake)

Seymen Area



Red = Damaged Buildings
Blue= Fires & Subsidence

Summary Comments

- Ultrafine Grid architecture supports orders of magnitude speedups over ray-tracing algorithms at virtually no accuracy reduction
- The PICMATCH4 co-registration algorithm is a more flexible tool
  - In combination with GTMOVE four dimensional search criteria available
  - Multi-sensor data co-registration demonstrated (EO,MSI,TI,INSAR)
- GRIDCOMP procedure supports iterative approach to co-registration
- TIECONV algorithm enhancements support Ultrafine Gridding of up to 1,000,000 points.
- GeoTIFF labels "direct" image co-registration and related processing
  - Map labels can be affine variant of map projection (systematic)
  - Map labels can be an approximate map projection (erratic)
- Additional capabilities could be supported:
  - Automated incorporation of solar illumination models during co-registration
  - Fly-thru visualizations (inverse of using DEM for co-registration)